A prototype multi-sensor kit for soil bulk density measurement using combined frequency domain reflectometry and visible and near infrared spectroscopy

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Abstract

Soil compaction created by different human and natural factors causes multiple environmental and agronomical problems. Many studies indicated increases in soil strength, bulk density (BD), and tillage draught requirement as a result of soil compaction, while decreases in soil total porosity, soil aeration, water infiltration and saturated hydraulic conductivity are evidence of soil compaction (Hamza and Anderson, 2005). A key requirement to manage soil compaction is the measurement of related properties that should be done quickly and cost effectively in the field without the need for laboratory analyses that are time consuming, difficult and slow procedures. Quraishi and Mouazen (2013a) introduced a multi-sensor platform, which enabled the assessment of BD from the fusion of data on penetration resistance measured with a load cell and gravimetric moisture content (ω), clay content and organic matter (OM) measured with a near infrared spectroscopy (NIRS) sensor. This multi-sensor does not measure volumetric moisture content (θv), necessary for the direct assessment of BD. Therefore, there is a need for a modified penetrometer sensing kit that enables simultaneous measurement of both θv and ω, and then derive BD values using Eqn. (1) (Wijaya *et al.*, 2004):

$$BD = \theta v/\omega \quad (1)$$

Where: BD is the soil bulk density in g cm^{-3}, θv is the volumetric moisture content in cm^3 cm^{-3} and ω is the gravimetric moisture content in g g^{-1}. The aim of this paper was to design and evaluate a CPSP, consisting of NIRS and FDR sensors. The developed CPSP kit will be tested for the measurement of the top soil BD under field measurement conditions

A combined-penetrometer sensor prototype (CPSP) for the measurement of topsoil BD was developed and tested under field conditions. The prototype consisted of a standard penetrometer, equipped with a NIRS (1650-2500 nm) to measure ω and a frequency domain reflectometry (FDR) to measure θv, while BD was assessed by the combination of both sensors' data. The CPSP was tested *in situ* at five arable and two grass fields of different soil texture classes in Silsoe, Bedfordshire, UK, during the period from June to December 2013. Artificial neural networks (ANN) were used to predict ω and θv based on data fusion of NIRS diffuse reflectance spectra and FDR output voltage (*V*), and the predicted values were substituted in Eqn. (1) to predict BD. The CPSP showed more accurate BD assessment in grass fields (RMSEp) of 0.077 g

cm^{-3}, compared to the arable fields (RMSEp of 0.104 g cm^{-3}), as shown in Table 1. A collective BD model produced for arable and grass fields' soils provided a moderate accuracy with a RMSEp of 0.102 g cm^{-3}. It can be concluded that the new CPSP can be used successfully to measure BD in the topsoil by combining the NIRS and FDR techniques through ANN-data fusion approach.

Table 1. Prediction results of volumetric moisture content (θv), gravimetric moisture content (ω) and bulk density (BD), obtained by using the combined-penetrometer sensor prototype (CPSP) in arable fields, grass fields and collective land use soils.

	Arable fields	**Grass fields**	**Collective**
***θ*v**			
R^2	0.97	1.00	0.94
RMSEp, cm^3 cm^{-3}	0.024	0.005	0.039
RPD	5.80	13.72	3.67
ω			
R^2	0.97	0.96	0.96
RMSEp, g g^{-1}	0.019	0.011	0.023
RPD	5.46	4.73	4.56
BD			
R^2	0.34	0.47	0.52
RMSEp, g cm^{-3}	0.104	0.077	0.102
RPD	1.08	1.36	1.21

R^2: coefficient of determination. RMSEp: root mean square error of prediction; and, RPD: residual prediction deviation, which is the standard deviation of laboratory measurement divided by RMSEp.

References:

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